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Discussion of "decentralized capacity management and internal pricing"

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Abstract Dutta and Reichelstein (2010) study the role of transfer pricing and organizational choice in providing incentives for efficient decisions on the acquisition and subsequent reallocation of capacity within decentralized firms. Their analysis suggests that transfer prices based on the historical cost of capacity facilitate the efficient allocation of resources. They also find that symmetric responsibility center structures are generally better suited for providing efficient investment incentives than hybrid organizations. An important condition for the derivation of the two results is the linearity of the shadow prices of capacity. If shadow prices are nonlinear, transfer prices should be below (above) the historical cost of capacity in order to counteract the managers' incentives to underinvest (overinvest). Because profit center organizations can use transfer prices for mitigating the inefficiency caused by nonlinear shadow prices, they offer a natural advantage over pure investment center organizations in implementing efficient capacity decisions. Overall, these observations suggest that the curvature of profit functions is an important factor in determining the suitable instruments for decentralized capacity management.

Keywords Capacity planning · Transfer pricing · Organizational form

JEL Classification M41 · D24 · D81

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1 Introduction

Sunil Dutta and Stefan Reichelstein (2010) (henceforth Dutta and Reichelstein) propose a model of capacity management in decentralized firms. The objective of their study is to identify robust mechanisms for implementing efficient decisions on the acquisition and subsequent reallocation of capacity between two divisions of a firm. The design variables for achieving this goal are the responsibility center structure and the transfer pricing policy.

The model offers a rich and complex structure. It distinguishes three organizational forms and two transfer pricing regimes and analyzes their efficiency for two capacity scenarios. The firm can either adopt a pure profit center structure, a pure investment center structure, or a hybrid organizational form in which one of the divisions is a profit center and the other becomes an investment center. The distinguishing feature between the two responsibility center types is that only investment centers have the right to acquire capacity. Transfer pricing becomes relevant whenever one of the divisions is organized as a profit center. The transfer pricing mechanism depends on the capacity type. Capacity can either be “dedicated” or “fungible”. In both cases the divisions can secure a certain capacity level at the beginning of each period but, only if capacity is fungible, the initial capacity assignments can later be reallocated between the two divisions. In both scenarios the initial transfer price per capacity unit is based on the historical acquisition cost of capacity. However, if capacity is fungible, the divisions are free to renegotiate the original agreement to their mutual advantage and adjust the transfer payment accordingly.

The key messages of the paper are as follows. First, transfer prices based on the historical cost of capacity can be a useful instrument for implementing efficient capacity decisions in decentralized organizations. Second, symmetric responsibility structures are generally better suited for providing efficient investment incentives than hybrid organizational forms. These findings are certainly interesting and relevant for the understanding of transfer pricing methods and the closely related question of organizational design.

An important condition for the optimality of full cost transfer pricing is the linearity of shadow prices in the fungible capacity scenario. Dutta and Reichelstein identify this limitation and derive the optimal capacity benchmark for nonlinear shadow prices. However, they do not formally analyze the consequences of this restriction on the firm’s transfer pricing policy and the ranking of organizational forms. My analysis suggests that it is generally better to use a transfer price that is unrelated to the historical cost of capacity when shadow prices are nonlinear. Indeed, the optimal transfer price is below (above) historical cost in order to counteract the divisions’ incentives to underinvest (overinvest). Moreover, because transfer prices are important for mitigating the inefficiency caused by nonlinear shadow prices, profit center organizations offer a natural advantage over pure investment center organizations in implementing efficient capacity decisions. I also demonstrate that the additional degree of freedom in guiding the divisions’ capacity decision can even make a hybrid organization more desirable than a pure investment center structure. Overall, these observations suggest that assumptions about the curvature of profit functions can have an important impact on capacity planning decisions under uncertainty and the transfer pricing problems related to them. This observation is an important by-product of the Dutta and Reichelstein model. On the one hand it significantly increases the complexity of transfer pricing models, but on the other hand it offers fruitful directions for future research in the area of transfer pricing.

The remainder of this discussion is organized as follows. Section 2 provides a short summary of the model and its main results. Section 3 reviews the relation between the Dutta and Reichelstein model and the existing literature in management accounting. Section 4 contains a detailed discussion of important assumptions and model limitations, and provides some suggestions for future research. Section 5 concludes the discussion with a short summary.

2 Summary of the model and its main results

2.1 Simplified model setup

In this section I explain the principal structure of the Dutta and Reichelstein model. I use a reduced version of their multiperiod model with a single capacity decision and a two-period planning horizon. This setup is convenient for the purpose of this discussion and facilitates the comparison of the Dutta and Reichelstein model with the existing literature. Consider a decentralized firm with a central office and $N = 2$ divisions. At the beginning of the planning horizon, the firm acquires b units of capacity at a constant unit cost of v. Capacity has a useful life of $T = 2$ periods, but it diminishes over time with a constant decay rate of $g(\beta) = 1 - \beta \in [0, 1]$. Hence, the available capacities in periods 1 and 2 are $k_1 = b$ and $k_2 = \beta \cdot b$.

The revenue of division i in period t is measured by the strictly concave function $R_{it} = R_i(q_{it}, \varepsilon_{it})$. The variable q_{it} denotes the actual amount of capacity allocated to division i in period t, and ε_{it} is a period-and division-specific revenue shock. The noise terms $\varepsilon_t \equiv (\varepsilon_{1t}, \varepsilon_{2t})$ are independent and uncorrelated over time. They materialize at the end of period t after the capacity for that period has been fixed.[1] Dutta and Reichelstein assume that the existing capacity is fully allocated to the two divisions and that the divisions never carry excess capacity. Thus, it always holds that $q_{1t} + q_{2t} = k_t$. From these assumptions, the expected total revenue in period t can be expressed as $M_t(k_t) \equiv \sum_i \widehat{R}_{it}$, where $\widehat{R}_{it} = E[R_i(q_{it}, \varepsilon_{it})]$ denotes the expected revenue of division i in period t. Let $\gamma = (1 + r)^{-1}$ denote the discount factor for an interest rate of r, then the present value of the firm's expected cash flows evaluated at $t = 0$ equals

$$\Pi_0 = \gamma \cdot M_1(b) + \gamma^2 \cdot M_2(\beta \cdot b) - v \cdot b. \tag{1}$$

Drawing on recent work of Rogerson (2008), Dutta and Reichelstein show that the multiperiod objective function in (1) can be decomposed into an intertemporally

[1] Dutta and Reichelstein define a second random variable θ_{it} in determining R_{it} in order to motivate the need for decentralized capacity planning. They assume that the two divisions jointly observe the realizations of θ_{it} at the beginning of each period but that this information is not available to the firm's headquarters. I ignore this variable for ease of notation.

Table 1 Overview of planning scenarios in Dutta and Reichelstein (2010)

Case	Capacity type	Organizational structure	Transfer price	Efficient delegation
1	Dedicated	Hybrid	Full cost	Yes
2	Fungible	Hybrid	Adjustable full cost (negotiated)	No
3	Fungible	Profit center	Adjustable full cost (negotiated)	Yes
4	Fungible	Investment center	Negotiated for reallocation of initial capacity	Yes

separable sum of period profits, $\Pi_0 = \sum_t \gamma^t \cdot \Pi_t$, where the expected profit for period t equals

$$\Pi_t = M_t(k_t) - c \cdot k_t, \quad \text{and} \quad c = \frac{v}{\gamma + \gamma^2 \cdot \beta}. \tag{2}$$

Since c is a linear function of the historical capacity acquisition cost, it can be interpreted as a period-related measure for the full cost per capacity unit.[2] The decomposition of the multiperiod objective function essentially allocates the historical capacity acquisition cost to the two periods of the budgeting cycle. In fact, the decomposition rule requires that $v \cdot b = c \cdot (\gamma \cdot k_1 + \gamma^2 \cdot k_2)$. After a rearrangement of terms, this identity can be taken to show that a share α of the historical capacity acquisition cost $v \cdot b$ is allocated to the first period, and a share $1 - \alpha$ is allocated to the second period, where

$$\alpha = \frac{1}{1 + \gamma \cdot \beta} = \frac{1 + r}{1 + r + \beta}. \tag{3}$$

From the definition of the cost allocation rule in (3), the share of the first period is decreasing in γ and β, and increasing in r, respectively. Moreover, the period cost measure c can equivalently be expressed as a linear function of the cost share, namely, $c = (\alpha/\gamma) \cdot v$.

Dutta and Reichelstein use this model framework to study the optimal acquisition and allocation of capacity within the decentralized firm. As shown in Table 1, they distinguish four scenarios that differ with respect to the degree of capacity commitment, the firm's organizational form and the transfer pricing scheme in place.

Dutta and Reichelstein distinguish three organizational forms. They start with a hybrid organization where division 1 acts as an investment center and division 2 is a profit center. In this setting division 1 is responsible for the acquisition of the total capacity required by the firm. Dutta and Reichelstein also study two pure organizational forms: A profit center organization and an investment center organization. In the profit center setting, the firm's headquarters acquires the

[2] In the context of the overlapping multiperiod planning problem in the Dutta and Reichelstein model, the term c can be interpreted as a measure for the long-run incremental cost per capacity unit, see Dutta and Reichelstein (2010).

capacity for both divisions, whereas in the investment center setting each division acquires its own capacity.

The capacity can either be dedicated or fungible. The hybrid organization is studied for both capacity types, whereas the analysis of the pure organizational forms assumes that capacity is fungible. The difference between the two scenarios is depicted in Fig. 1 for the hybrid organization. In both cases division 2 first reserves an initial capacity level k_{2t} at the beginning of each period. Subsequently division 1 determines its own capacity requirement, aggregates the divisional capacity demands, and acquires total capacity b_t. If capacity is fungible, the two divisions renegotiate a reallocation of the initially reserved capacity levels to their mutual advantage after observing the period specific revenue shock vector ε_t. Hence, $k_{it} \neq q_{it}$ in the fungible capacity scenario except for hairline cases. If capacity is dedicated, the period specific revenue shock vector ε_t is observed too late for adjusting the initial capacity assignments, so that the divisions are forced to use the initially reserved capacity levels for production, that is $k_{it} = q_{it}$.

For the dedicated capacity scenario, Dutta and Reichelstein consider a system of transfer prices based on the historical acquisition cost of capacity. This full-cost transfer price also serves as a starting point for the "adjustable full cost" transfer pricing scheme in the fungible capacity scenarios 2 and 3. Here, the divisions order their initial capacities at full cost but adjust the transfer payment during renegotiations. For the investment center organization (case 4), there is initially no need for transfer pricing, but the transfer payments for capacity reallocations are determined through bilateral negotiations between the two divisions.

In order to evaluate the efficiency of the proposed organizational settings and transfer pricing schemes, Dutta and Reichelstein focus on the notion of goal congruence between headquarters and the two divisions. Managers are assumed to make their capacity decisions in order to maximize their expected divisional performance. A divisional performance measure is congruent with the objectives of the firm whenever it motivates the division manager to maximize the firm's multiperiod objective function in (1). Strong goal congruence is achieved if both managers have an incentive to maximize the multiperiod objective function of the firm regardless of their own time preferences. Dutta and Reichelstein allow for

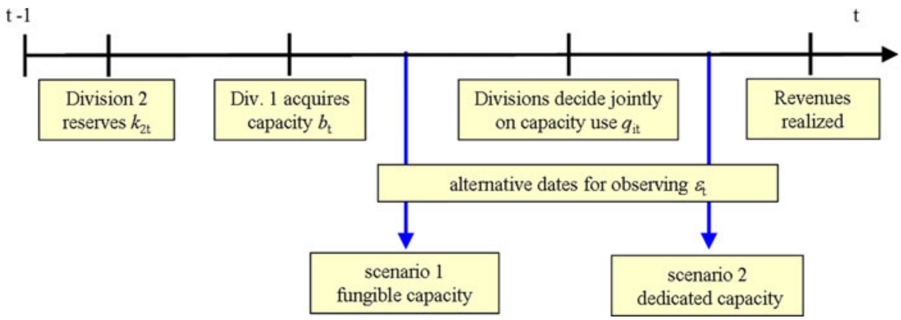

Fig. 1 Sequence of decisions and information flow in the fungible and the dedicated capacity scenario for a hybrid organization

arbitrary managerial time preferences. They assume that the manager of divison i maximizes a weighted average $\sum_t u_{it} \cdot \Pi_{it}$ of the expected period performances Π_{it}, where u_{it} denotes a non-negative weight attached to the performance of period t.

2.2 Main results

Achieving strong goal congruence in a multiperiod transfer pricing problem is a nontrivial exercise because it requires an efficient decomposition of the firm's multiperiod objective function into $N \times T$ independent divisional performance measures. Thus, in contrast to a traditional single period transfer pricing problem, a cross sectional disaggregation of the firm profit into N independent divisional profit maximization problems is not sufficient for an efficient decentralization. In addition, the multiperiod framework also requires the intertemporal independence between the divisional performance measures over time. Nevertheless Dutta and Reichelstein find that strong goal congruence can be attained for all organizational structures under consideration except for the hybrid organization in the fungible capacity scenario.

As noted above, the multiperiod objective function in (1) can be disaggregated into T independent profit function at the firm level. Since $q_{1t} + q_{2t} = k_t$ and $q_{it} = k_{it}$, the firm's total expected cash flow for the dedicated capacity scenario is maximized if capacities are determined so that the expected marginal revenue of division i in period t, $\widehat{R}'_{it}$, equals the full period cost per capacity unit:

$$\widehat{R}'_{it}(k_{it}) = c. \tag{4}$$

Let k^d_{it} denote the capacity level that solves (4), then the efficient capacity level for period t in the dedicated capacity scenario equals $k^d_t = k^d_{1t} + k^d_{2t}$. If division 2 is organized as a profit center and division 1 acts as an investment center, the divisional performance measures are given by the following expressions:

$$\Pi_{2t} = \widehat{R}_{2t}(k_{2t}) - p \cdot k_{2t} \tag{5}$$

$$\Pi_{1t} = \widehat{R}_{1t}(k_{1t}) + p \cdot k_{2t} - c \cdot (k_{1t} + k_{2t}), \tag{6}$$

where p denotes the transfer price per capacity unit. It can be seen that the divisional performance measures in (5) and (6) are maximized by the efficient capacity levels k^d_{it} whenever the transfer price equals the full period cost of capacity, that is, if $p = c$.

If capacity is fungible, the existing capacity can be reallocated between divisions after the revenue shock vector ε_t has materialized. The optimal amount of capacity allocated to division i after renegotiation, $q^*_{it} \equiv q_{it}(k_t, \varepsilon_t)$, is found by maximizing the sum of the realized revenues subject to the condition that $q_{1t} + q_{2t} = k_t$. It is implicitly defined by the following optimality condition

$$R'_{it}\left(q^*_{it}, \varepsilon_{it}\right) = \lambda(k_t, \varepsilon_t), \quad i = 1, 2. \tag{7}$$

$R'_{it}(\cdot)$ denotes marginal revenue, and $\lambda(k_t, \varepsilon_t)$ is the Lagrangian multiplier measuring the shadow price of capacity for a given capacity stock k_t and a given realization of the random vector ε_t. Substituting the optimally reallocated capacity levels into the divisional revenue functions yields a maximum revenue of $R^*_{it} = R_i(q_{it}(k_t, \varepsilon_t), \varepsilon_{it})$ for division i in period t and an ex ante expected maximum revenue of $\widehat{R}^*_{it} = E[R_i(q_{it}(k_t, \varepsilon_t), \varepsilon_{it})]$. Let $M^*_t(k_t) \equiv \sum_i \widehat{R}^*_{it}$, then the present value of the firm's expected cash flow evaluated at $t = 0$ equals

$$\Pi^*_0 = \gamma \cdot M^*_1(b) + \gamma^2 \cdot M^*_2(\beta \cdot b) - v \cdot b. \tag{8}$$

As in the dedicated capacity scenario, the multiperiod objective function in (8) can be decomposed into an intertemporally separable sum of period profits, $\Pi^*_0 = \sum_t \gamma^t \cdot \Pi^*_t$, where the expected profit for period t equals

$$\Pi^*_t = M^*_t(k_t) - c \cdot k_t. \tag{9}$$

Since $\partial M^*_t(k_t)/\partial k_t = E[\lambda(k_t, \varepsilon_t)]$ from the envelope theorem, the firm's total expected profit for the fungible capacity scenario in (8) is maximized if the following condition holds for all periods:

$$\partial \Pi^*_t / \partial k_t = E[\lambda(k_t, \varepsilon_t)] - c = 0. \tag{10}$$

Let k^o_t denote the aggregate capacity level that solves (10) and let k^o_{it} be the efficient capacity level for division i. A comparison of the optimality conditions for the dedicated and the fungible capacity scenarios in (4) and (10) indicates that $k^o_t = k^d_t$ and $k^o_{it} = k^d_{it}$ if and only if the following condition holds:

$$\widehat{R}'_{it}(k^d_{it}) = E\left[\lambda(k^o_t, \varepsilon_t)\right] \quad \forall \quad i, t. \tag{11}$$

That is, the optimal capacities for the two alternative demand scenarios are identical if the optimality condition for reallocating capacities after observing the noise term vector ε_t in (7) also holds in expectation. Dutta and Reichelstein implicitly employ condition (11) for the main part of their paper by assuming that divisional revenues and the shadow price λ (k_t, ε_t) are linear functions of the random variables ε_{it}.

To illustrate the consequence of linear shadow prices, I consider an example with quadratic revenue function $R_{it} = (\theta + \varepsilon_i) \cdot q_{it} - 0.5 \cdot q^2_{it}$ and $E[\varepsilon_i] = 0$.[3] With these assumptions the expected marginal revenue in the dedicated capacity scenario equals $\widehat{R}'_{it}(k_{it}) = \theta - k_{it}$, so that $k^d_{it} = \theta - c$ from (4) and $k^d_t = 2 \cdot k^d_{it}$ by the symmetry of divisional revenues. The solution in the fungible capacity scenario is derived in two steps. First, reallocating a given total capacity of k_t yields optimal capacity assignments of $q^*_{it} = 0.5 \cdot (k_t + \varepsilon_i - \varepsilon_j)$ and a shadow price of $\lambda(k_t, \varepsilon_t) = \theta - 0.5 \cdot (k_t - \varepsilon_1 - \varepsilon_2)$. It can be seen that λ (k_t, ε_t) is a linear function of ε_1 and ε_2. Second, taking the expectation of the shadow price and applying condition (10) results in an optimal capacity of $k^o_t = 2 \cdot (\theta - c)$. It follows that $k^o_t = k^d_t$. Moreover, taking this solution, the expected capacity assignments for the fungible capacity scenario become $E\left[q^*_{it}\right] = 0.5 \cdot k^o_t = k^d_{it}$. That is, in expectation the same amount of capacity is allocated to the two divisions under both scenarios. Finally, it can be seen that condition (11) collapses to $k_{it} = 0.5 \cdot k_t$. This equation holds only if $k_{it} = k^d_{it}$.

For inducing the managers to replicate the optimal solution in the fungible capacity scenario, Dutta and Reichelstein propose a negotiated transfer pricing

[3] The quadratic revenue function of the example obtains, for example, if one assumes a linear inverse demand function with additive noise: $p_{it}(q_{it}) = \theta + \varepsilon_i - 0.5 \cdot q_{it}$.

scheme in the spirit of Edlin and Reichelstein (1995) and refer to this method as adjustable full cost transfer pricing. The mechanism allocates the initial capacity endowment at historical cost but after the divisions observe the realization of the random vector ε_t, they renegotiate the initial allocation by adjusting the originally assigned amounts k_{it} to the optimal capacity levels q^*_{it}. The resulting surplus is split between the divisions through lump sum transfer payments in proportion to their bargaining power δ_i, where $\delta_1 = 1 - \delta_2$. Ex ante, the expected renegotiation surplus equals $SP_t(k_t) = M^*_t(k_t) - M_t(k_t)$. A rational division manager correctly anticipates the outcome of the renegotiation stage and accounts for it in making his capacity decision. For a pure profit center organization, the performance measure of division i in period t becomes

$$\Pi_{it} = \widehat{R}_{it}(k_{it}) - p \cdot k_{it} + \delta_i \cdot SP_t(k_t). \tag{12}$$

Maximizing the expression in (12) with respect to k_{it} and rearranging terms yields the following first-order condition for division i in period t:

$$\Pi'_{it} = \partial \Pi^*_t / \partial k_t - (p - c) - (1 - \delta_i) \cdot \left(E[\lambda(k_t, \varepsilon_t)] - \widehat{R}'_{it}(k_{it}) \right) = 0. \tag{13}$$

In each period the equilibrium capacities $k^*_t = \left(k^*_{1t}, k^*_{2t}\right)$ are obtained by solving the pair of equilibrium conditions in (13) for k_{1t} and k_{2t}. Comparing the equilibrium condition in (13) with the condition for the efficient capacity choice in (10) shows that in equilibrium $k^*_{it} = k^o_{it}$ if the central office sets $p = c$ and if condition (11) holds. Thus, in a pure profit center organization, it is essential for an efficient delegation of capacity planning that the transfer price is at full cost and that the shadow prices are linear in ε_t. Moreover, with linear shadow prices, this result is independent of the divisions' individual bargaining power because in equilibrium the expected marginal return from reallocating the initial capacity levels, $E\left[\lambda\left(k^*_{it} + k^*_{jt}, \varepsilon_t\right)\right] - \widehat{R}'_{it}\left(k^*_{it}\right)$, is zero. The same observations can be made for an investment center organization, where the performance measure of division i becomes

$$\Pi_{it} = \widehat{R}_{it}(k_{it}) - c \cdot k_{it} + \delta_i \cdot SP_t(k_t). \tag{14}$$

However, since both divisions are responsible for acquiring their own capacity, there is initially no need for transfer pricing. Both divisions will incorporate the historical acquisition cost of capacity into their investment decision. A comparison of the performance measures in the pure profit center and the pure investment center settings in (12) and (14) shows that both divisions face identical decision problems in every period whenever $p = c$. Thus, charging a profit center the full period cost of capacity puts it into the position of an investment center.

It follows that the firm has two alternatives for achieving efficiency in the fungible capacity scenario: a pure profit center organization and a pure investment center organization. By contrast, the hybrid organization can cause problems in the fungible capacity scenario because the manager of the downstream division may have incentives to strategically distort his capacity demand. I will discuss this case in detail in Sect. 4.2.

3 Relation and contribution to the management accounting literature

3.1 Efficiency of full-cost-based (transfer) pricing decisions

The relevance of full cost for (transfer) pricing decisions is one of the most fundamental issues in management accounting research. On the one hand it is a well documented empirical fact that firms frequently use full-cost-based product and transfer prices.[4] On the other hand it is widely accepted in the management accounting literature that full cost is not relevant for operating decisions. As a matter of fact, the acquisition cost of capacity is only relevant for the procurement decision but not for the subsequent decisions on the optimal use of the existing capacity resources. These decisions should rather be guided by the current opportunity cost of capacity at the time of the resource usage decision.

The apparent conflict between theory and practice has motivated a considerable amount of research aiming to rationalize the use of full cost measures for product and transfer pricing decisions. The recent transfer pricing literature has focused on the role of full-cost-based transfer prices as a decision influencing device. For example, one line of research proposes cost-based transfer prices for mitigating adverse selection problems (Wagenhofer 1994; Vaysman 1996; Christensen and Demski 1998). A second stream of research examines the usefulness of cost-based transfer prices in providing incentives for specific investments at the divisional level (Baldenius et al. 1999; Sahay 2003; Pfeiffer et al. 2008; Baldenius 2009). A third group of articles studies the strategic role of transfer prices above marginal cost as a commitment device vis-a-vis a competitor in a duopolistic product market (Alles and Datar 1998, Göx 2000, Narayanan and Smith 2000).[5]

The structure of the capacity planning problem in the Dutta and Reichelstein model is closely related to a strand of literature that examines the formal relation between firms' capacity planning and pricing decisions. The capacity planning and pricing literature focuses on identifying conditions under which the historical cost of capacity approximates the current opportunity cost without economic loss.[6] The starting point of the capacity planning and pricing literature is the model of Banker and Hughes (1994). They consider a simultaneous capacity planning and pricing problem of a multiproduct monopolist facing uncertain demand and find that pricing and capacity decisions can efficiently be decomposed if capacity units are allocated at the historical acquisition cost per capacity unit.[7]

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[4] See e.g. Govindarajan and Anthony (1983) and Shim and Sudit (1994) for evidence on the role of full cost in product pricing. Horngren et al. (2005) provide a summary of international evidence on full-cost-based transfer pricing.

[5] See Göx and Schiller (2007) for a detailed survey of the economic transfer pricing literature and for further references.

[6] See Balakrishnan and Sivaramakrishnan (2002) for a survey of the capacity planning and pricing literature.

[7] Budde and Göx (1999) establish a similar result in the context of a procurement auction. Göx (2001) considers a two-period version of the capacity planning and pricing model and identifies conditions under which full cost pricing can serve as a suitable heuristic.

Göx (2002) generalizes the model of Banker and Hughes (1994). He considers a sequential capacity planning and pricing model that distinguishes three different demand scenarios. As shown in Fig. 2, the firm sets capacity k at $t = 1$ and product price m at $t = 2$. The demand function, $q(m, \varepsilon) = a - m + \varepsilon$, is linear and contains a noise term ε with mean zero. The three demand scenarios vary in the time at which the firm learns the realization of the noise term ε. In the first scenario, the firm observes ε at the beginning of the budgeting cycle and decides under certainty on k and m. In the second scenario, the firm learns ε after choosing k and m, so that both decisions are taken under uncertainty. Finally, in the third scenario, the firm learns ε after choosing k but before setting m. Göx (2002) refers to this third scenario as "partial uncertainty" because only the capacity decision is made under uncertainty, whereas the pricing decision is taken under certainty.

Based on the analysis of the optimal capacity planning and pricing policies for the three scenarios Göx (2002) shows that the differential availability of demand information is crucial for determining the relevance of historical capacity cost for pricing. In fact, whenever the firm has access to the same demand information at the time of capacity planning and pricing, it factors the historical capacity cost into the optimal pricing formula. This solution obtains under certainty and under uncertainty but not under partial uncertainty. The intuition behind this result can best be explained for the certainty scenario. Consider first the pricing decision for a given capacity level k. Let $R(m, \varepsilon) = m \cdot q(m, \varepsilon)$ denote revenue and v the cost per capacity unit. The firm maximizes total profit $\Pi(m,k) = R(m,\varepsilon) - v \cdot k$ with respect to m subject to the constraint that $k \geq q(m, \varepsilon)$. The optimal product price m^* is found by equating marginal revenue with the opportunity cost of capacity, measured by the Lagrangian multiplier $\lambda(k, \varepsilon)$. Since it cannot be rational to waste resources under perfect foresight, the firm sets its capacity so that $k = q(m^*, \varepsilon)$ and $\lambda(k, \varepsilon) = v$. Hence, the optimal policy can be characterized by the following condition:

$$R'(m,\varepsilon) = \lambda(k,\varepsilon) = v. \tag{15}$$

The first part of the optimality condition in (15) is equivalent to (7). The second part suggests that, under certainty, the historical capacity acquisition cost incurred at $t = 1$ is a perfect substitute for the opportunity cost of capacity determined on the

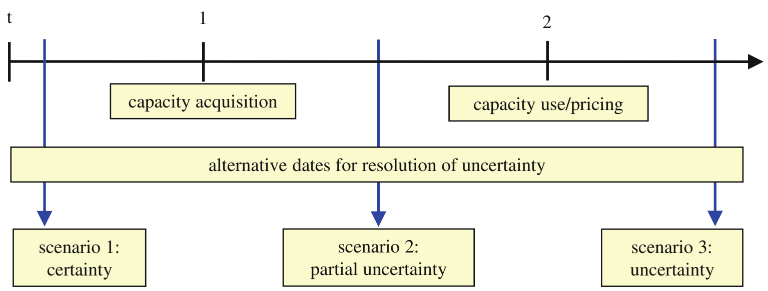

Fig. 2 Sequence of decisions and information flow in the capacity planning and pricing model of Göx (2002)

basis of the demand information available at $t = 2$. It follows that the pricing problem can be simplified by directly setting $k = q(m, \varepsilon)$ and maximizing the unconstrained profit $\Pi(m) = (m - v) \cdot q(m, \varepsilon)$ with respect to m. A similar argument can be made for the uncertainty scenario. Here, optimal capacity and product price are found as the solution of a modified newsboy problem. As shown by Banker and Hughes (1994), the optimal capacity equates the historical acquisition cost with the expected opportunity cost of capacity. At the same time the optimal price equates the expected opportunity cost of capacity with expected marginal revenue. Taken together, both conditions imply that the optimal price can be found independent of the optimal capacity by maximizing the modified profit function $E[\Pi(m)] = (m - v) \cdot E[q(m, \varepsilon)]$ with respect to m.[8] The sole difference between the simplified profit functions in the certainty and uncertainty scenario consists of replacing actual with expected revenue.

Unfortunately, such simplification cannot be made for the partial uncertainty scenario. Here, the solution of the pricing problem is identical to the certainty scenario. The optimal price is found by equating marginal revenue with the opportunity cost of capacity. However, because $\lambda(k, \varepsilon)$ is a function of ε but capacity is chosen before ε is observed, the optimal capacity balances the historical acquisition cost with the expected opportunity cost of capacity. Since $E[\lambda(k, \varepsilon)] \neq \lambda(k, \varepsilon)$, it is impossible to establish a functional relation between the historical acquisition cost incurred at $t = 1$ and the opportunity cost determined at $t = 2$. Accordingly, a pricing policy based on the historical cost of capacity fails to maximize the firm's profit.

The optimality conditions for capacity acquisition and pricing (capacity use) for the uncertainty and the partial uncertainty scenario are summarized in Table 2. The table compares the relevant scenarios of the capacity planning and pricing model with the benchmark solutions for the two capacity scenarios in Dutta and Reichelstein. A closer inspection of the decision sequences and information flows in Figs. 1 and 2 suggests that the partial uncertainty scenario in the capacity planning and pricing model has the same structure as the fungible capacity scenario in the Dutta and Reichelstein model. In both models, the capacity is acquired before the demand uncertainty resolves but capacity use is optimized afterwards. Likewise, in both cases the optimal capacity is determined by equating the historical acquisition cost with the expected opportunity cost of capacity, whereas the use of existing capacity is optimized by equating marginal revenue with the actual opportunity cost of capacity.

A similar observation can be made for the uncertainty and the dedicated capacity scenario. Here, the decisions on capacity acquisition and capacity use are essentially made before the demand uncertainty resolves. However, in the Dutta and Reichelstein model the capacity usage decision is not explicitly modeled but implicitly determined when the divisions decide on their initial capacity endowments k_{it}. Nevertheless, in conjunction with the optimality condition for pricing the

[8] As shown by Göx (2002), the full separation of the pricing problem from the capacity planning problem actually requires "soft" capacity constraints as assumed by Banker and Hughes (1994). With "hard" capacity constraints, the optimal price can still be characterized as full cost-based, but the optimal solution for p and k must be determined simultaneously.

Table 2 Comparison of optimal decision rules for capacity acquisition and capacity use in the capacity planning and pricing (CPP) model and the Dutta and Reichelstein (DR) model

Scenario class	CPP model	DR model
I	Uncertainty	Dedicated capacity
Capacity use	E[MR] = E[OC]	Not explicitly modeled
Capacity acquisition	HC = E[OC]	HC = E[MR]
II	Partial uncertainty	Fungible capacity
Capacity use/reallocation	MR = OC	MR = OC
Capacity acquisition	HC = E[OC]	HC = E[OC]

The table shows the first order conditions for capacity use and capacity acquisition in four different planning scenarios. *MR* marginal revenue, *OC* opportunity cost of capacity, and *HC* historical cost of capacity. *E[MR]* and *E[OC]* expected marginal revenue and expected opportunity cost, respectively

condition determining the optimal capacity in the capacity planning and pricing model is equivalent to the condition for the optimal capacity choice in the Dutta and Reichelstein model. Namely, the historical acquisition cost must equal the expected opportunity cost capacity.

Given these similarities, both models consistently recommend that optimal decisions on capacity use (pricing) at the firm level can be based on the historical cost of capacity if the revenue uncertainty resolves after the capacity usage decision but not if additional demand information arrives between the decisions on capacity acquisition and capacity use. However, due to their focus on decentralization, Dutta and Reichelstein go one step further than the capacity planning and pricing model and demonstrate that historical capacity cost can even play an important role for the efficient allocation of capacity in decentralized firms if they are not relevant for deciding on capacity usage at the firm level. As shown in Sect. 2.2, the adjustable full cost transfer pricing mechanism facilitates an efficient decentralization in the fungible capacity scenario if the division are organized as profit centers. This solution requires that the transfer price at which the divisions can reserve their initial capacity endowment equals the historical cost of capacity. Otherwise, the divisions would have incentives to reserve inefficient capacity levels in the first place. For example, an ex ante transfer price below the historical cost of capacity ($p < c$) would act as a subsidy and motivate both divisions to overinvest even if condition (11) holds.

Overall, the results of the Dutta and Reichelstein model suggest that the historical cost of capacity are an integral part of an efficient capacity management in multidivisional firms, even in cases where they are not useful for operational decisions at the firm level. This result is an interesting and novel contribution to the transfer pricing literature and, more generally, to the full costing debate.

3.2 Transfer pricing and organizational form

The analysis of transfer pricing is closely related to the organization of the firm. Most transfer pricing models assume, implicitly or explicitly, that a decentralized organization is beneficial and analyze transfer prices as an instrument for coordinating the decisions of the division managers in the best interest of the firm.[9] For example, the standard transfer pricing model (Hirshleifer 1956) assumes a profit center structure and recommends transfer prices at marginal cost in order to implement an efficient level of internal trade between the divisions. This solution leaves open why the firm actually uses transfer prices for coordinating interdivisional trade. In fact, the firm's central office must know the optimal transfer quantity to determine the optimal transfer price so that it could equally regulate the trade quantity directly instead of using a pricing mechanism for arriving at the same solution. More fundamentally, the standard transfer pricing model does not provide a clear economic rationale for decentralization because a centralized firm can also allocate resources efficiently.[10]

In line with most recent work that analyzes transfer pricing in terms of an incomplete contracting problem, Dutta and Reichelstein assume that the need for decentralization arises from revenue information on the part of the division managers that is not available to the firm's headquarters. This assumption seems generally appropriate but, for the sake of completeness, it should be mentioned that it requires some sort of limited communication between headquarters and divisions in order to rule out the application of the revelation principle.[11]

An important feature of the Dutta and Reichelstein model is that it allows to compare a broader set of responsibility center structures in the context of an otherwise classical transfer model. So far, only few transfer pricing models have adopted a similar approach, most of them consider only a single organizational form. A well known exception is the model of Holmström and Tirole (1991). They study the effectiveness of four different organizational forms in the context of a holdup model, but they do not provide generalizable recommendations on the optimal responsibility center structure. In the Dutta and Reichelstein model, organizational choice becomes relevant in the fungible capacity scenario. Here, an efficient reallocation of the initially reserved capacity levels can be attained through the proposed adjustable full cost transfer pricing mechanism if the firm adopts one of the two pure organizational forms. By contrast, Dutta and Reichelstein find that the hybrid organization suffers from a dynamic holdup problem that arises if the manager of the downstream division strategically distorts his capacity demand. In other words, a balanced responsibility center structure seems generally more desirable than an unbalanced allocation of decision rights.

9 An important exception are strategic transfer pricing models (Göx 2000, Narayanan and Smith 2000). In these models decentralization is key for committing managers to adopt product market strategies that would not be credible for centralized firms.

10 If there is a competitive market for the intermediate input, the transfer price should equal the market price (Hirshleifer 1956). However, with this solution there is neither an advantage of internal trade nor a reason for vertical integration.

11 See e.g. Vaysman (1996) for a detailed analysis of this argument.

This clear result holds only for linear shadow prices. The ranking of organizational forms for nonlinear shadow prices is left open and deserves further consideration. Likewise, it seems promising to investigate factors that might constitute a preference ordering over the two pure organizational forms. An obvious advantage of a profit center organization over an investment center structure is the very fact that the firm's central office controls the transfer price p at which the divisions reserve their initial capacity endowments. As shown in Sect. 2.2, this additional degree of freedom does not help to distinguish the two organizational forms in the basic version of the Dutta and Reichelstein model because the optimal transfer price equals the historical capacity cost c. By making the profit center manager responsible for the full cost of the capacity investments that the firm makes on his behalf, this solution essentially converts the profit center into an investment center.

The principal factor distinguishing investment centers from other types of responsibility centers is the right to make autonomous investment decisions. Although Dutta and Reichelstein point to technical expertise as a possible reason for giving authority over the acquisition of capacity resources to the divisions managers, their model offers no endogenous advantage for establishing an investment center structure. One path for extending the model into that direction would be the introduction of asymmetric information regarding the acquisition cost of capacity. If only the division manager(s) would be able to verify the actual cost of capacity investments, the decentralization of capacity decisions would offer a natural advantage over a centralized acquisition of resources. At the same time this extension would give rise to a potential conflict of interest between headquarters and divisions and thereby create an interesting trade-off between the two pure organizational forms under considerations.

4 Selected issues and possible extensions

4.1 Nonlinear shadow prices

An important restriction of the basic model is the linearity of shadow prices. As shown in Sect. 2.2, the linearity assumption entails the identity of optimal capacities in the two alternative scenarios and thereby eliminates the potential distortions arising from the split of the renegotiation surplus in the fungible capacity scenario. If shadow prices are nonlinear it holds that

$$\widehat{R}'_{it}\left(k^d_{it}\right) \neq E\left[\lambda\left(k^o_t, \varepsilon_t\right)\right]. \tag{16}$$

Condition (16) implies that the efficient capacity for the fungible capacity scenario in (10) is different from the optimal capacity in the dedicated capacity scenario in (4), that is, $k^o_t \neq k^d_t$. As a consequence, the adjustable full cost mechanism is no longer sufficient for an efficient decentralization of capacity planning. Dutta and Reichelstein clearly identify this limitation, but they do not formally analyze alternative transfer pricing methods or the consequences of nonlinear shadow prices on the ranking of organizational forms. The consequences of nonlinear shadow prices on the divisions' capacity decisions can be shown by a closer inspection of the equilibrium conditions for a pure profit center structure in (13). Setting $p = c$ and evaluating these conditions for the efficient capacity level yields the following expression for division i

$$\Pi'_{it}\left(k^o_{it}, k^o_t\right) = -(1-\delta_i)\cdot\left(E\left[\lambda\left(k^o_t, \varepsilon_t\right)\right] - \widehat{R}'_{it}\left(k^o_{it}\right)\right), \tag{17}$$

where $k^o_t = k^o_{1t} + k^o_{2t}$. From (16), the expression in (17) is nonzero unless division i would be able to capture the entire renegotiation surplus. In fact, if $\delta_1 = 1$ and $\delta_2 = 0$ the equilibrium conditions for division 1 and 2 become

$$E[\lambda(k_{1t} + k_{2t}, \varepsilon_t)] = c \quad \text{and} \quad \widehat{R}'_{2t}(k_{2t}) = c. \tag{18}$$

The unique equilibrium capacities solving (18) are $k^*_{2t} = k^d_{2t}$ and $k^*_{1t} = k^o_t - k^d_{2t}$. That is, division 2 reserves the optimal quantity for the dedicated capacity scenario and division 1 adjusts its capacity demand so that in total the optimal capacity k^o_t is acquired. Intuitively this solution obtains because division 1 becomes the residual claimant of the firm, whereas division 2 anticipates that it will not participate in the renegotiation surplus.

For general values of $\delta_i \in (0, 1)$, both divisions will underinvest in capacity if $E\left[\lambda\left(k^o_t, \varepsilon_t\right)\right] > \widehat{R}'_{it}\left(k^o_{it}\right)$ and overinvest otherwise.[12] The firm can mitigate this problem if it modifies the transfer pricing policy. It can be seen from the equilibrium condition in (13) that an increase of p reduces the capacity demand of division i for a given capacity demand of division j. Likewise, a reduction of p will provide incentives for both divisions to increase their capacity demands. The firm's central office can build on these effects and use the transfer price to adjust the divisions' investment incentives.

It can be shown that there exists a transfer price p^o that induces both divisions to choose the efficient investment levels. This transfer price is below (above) the historical capacity acquisition cost if the firm needs to counteract an underinvestment (overinvestment) problem. However, in order to determine the optimal transfer price, the central office must know the divisional revenue functions. Even if the firm's headquarters cannot verify the actual revenues, as it is assumed by Dutta and Reichelstein, the firm may still be able to calculate the transfer price on the basis of its expectations about the shape of the revenue function. This approach will generally not lead to efficient capacity investments, but it is very likely that it generates higher profits than the adjustable full cost transfer pricing mechanism.

As argued in Sect. 3.2, only a profit center structure allows the firm to adjust the transfer price for improving the divisions' investment incentives. By contrast, a pure investment center organization offers no instrument for avoiding the inefficiency caused by nonlinear shadow prices. It follows that a pure profit center organization weakly dominates a pure investment center organization. The former organizational structure can always replicate the investment incentives provided by the latter by

[12] DR show that for a revenue function of the form $R_{it} = \varepsilon_{it} \cdot R_{it}(\theta_{it}, q_{it})$ the divisions will overinvest whenever $\lambda(k_t, \varepsilon_t)$ is concave in ε_t, and underinvest if $\lambda(k_t, \varepsilon_t)$ is convex in ε_t.

setting $p = c$, but in some cases it can improve the situation by using a transfer price $p \neq c$.

The following example illustrates the consequences of nonlinear shadow prices. Let division i have a quadratic revenue function $R_i = \theta_i \cdot q_i - 0.5 \cdot \varepsilon_i \cdot q_i^2$, where $\varepsilon_i \in \{1, 2\}$ with equal probability.[13] Also, let $\theta_i = 300$ and $c = 45$ for computing numerical solutions. With these assumptions the expected marginal revenue in the dedicated capacity scenario equals $\widehat{R}_i'(k_i) = 300 - 1.5 \cdot k_i$. Equating this expression with cost yields an optimal capacity of $k_i^d = 170$ for division i and a total capacity level of $k^d = 340$.

For the fungible capacity scenario the solution begins with the optimal reallocation of total capacity k. The constrained profit maximization problem yields optimal capacity assignments of $q_i^* = \varepsilon_i \cdot k/(\varepsilon_1 + \varepsilon_2)$ and a shadow price of $\lambda(k, \varepsilon) = [300 \cdot (\varepsilon_1 + \varepsilon_2) - k \cdot \varepsilon_1 \cdot \varepsilon_2]/(\varepsilon_1 + \varepsilon_2)$. Since $\partial^2 \lambda(k, \varepsilon)/\partial \varepsilon_i^2 < 0$, the shadow price is strictly concave in ε_i. Taking the expectation of the shadow price yields $E[\lambda \ (k, \varepsilon)] = 300 - (17/24) \cdot k$ and an optimal capacity of $k^o = 360$ from condition (10). It can be seen that $k^o - k^d = 20$, that is, the firm installs more capacity if it can be reallocated after observing ε. Substituting the expressions for the expected shadow price and the expected marginal revenue for the dedicated capacity scenario into (13) yields the following equilibrium conditions for the example:

$$\Pi_i'(k_i, k_j) = 300 - 1.5 \cdot k_i - p + \delta_i \cdot \left(\frac{19 \cdot k_i - 17 \cdot k_j}{24} \right) = 0, \quad i,j = 1,2, \ i \neq j. \tag{19}$$

Solving the system of equations in (19) for k_1 and k_2 and substituting $p = c$ yields the equilibrium capacity levels for the adjustable full cost mechanism or, equivalently, for an investment center structure. As argued above, these capacities will generally be too low. For example, for identical bargaining powers ($\delta_i = 0.5$) both divisions will reserve a capacity of $k_i^* = 174.86$. The resulting total capacity of 349.72 lies between the optimal capacities for the dedicated and the fungible capacity scenario.

With adjustable full cost transfer pricing, efficiency can only be attained if one of the divisions has all bargaining power. For example, if $\delta_1 = 1$, division 2 reserves $k_2^* = 170$, division 1 reserves $k_1^* = 190$, and the total capacity equals the efficient level of $k^o = 360$. However, if both divisions can capture a part of the renegotiation surplus, efficient investment can be induced by setting the transfer price equal to $p^o = 45 - 30 \cdot \delta_i \cdot (1 - \delta_i)$. The transfer price is lower than c for $\delta_i \in (0, 1)$ in order to motivate the divisions to increase their capacity demands. It takes a minimum value of $p^o = 37.5$ for identical bargaining powers ($\delta_i = 0.5$). For this value, both divisions reserve capacities of $k_i^* = k^o/2$. It can also be seen that the optimal transfer price equals $c = 45$ for $\delta_i = 1$. Only for this case an initial transfer at full capacity cost induces efficient capacity investments if shadow prices are nonlinear.

[13] To economize on notation, I consider a representative period and supress the time index.

The equilibrium in the divisions' capacity acquisition game for the case of identical bargaining powers is depicted in Fig. 3. The intersection point between the two reaction functions $k_1^*(k_2, c)$ and $k_2^*(k_1, c)$ in point N marks the equilibrium capacities for a transfer at full cost $\left(k_i^* = 174.86\right)$. If the firm's central office charges a transfer price of $p^o = 37.5$, the reaction functions are shifted to the northeast. The new reaction functions $k_1^*(k_2, p^o)$ and $k_2^*(k_1, p^o)$ intersect at the new equilibrium point E where both divisions reserve exactly half of the efficient capacity. Finally, the line between E_1 and E_2 depicts all efficient combinations of k_1 and k_2. The boundary points are equivalent to the equilibrium points that would obtain if one of the two divisions had all bargaining power.

4.2 Hybrid organization with fungible capacity

So far, the discussion has focused on the two pure organizational forms. As shown in Table 1, Dutta and Reichelstein also evaluate the efficiency of a hybrid organization for the fungible capacity scenario and find that it suffers from a dynamic holdup problem. This problem arises in the hybrid organization if division 2 anticipates that it might pay to inflate its capacity demand in early periods in order to obtain a part of the resulting excess capacity in later periods during negotiations. In the context of the two-period model, the multiperiod objective function of division 2 is given by the following expression:

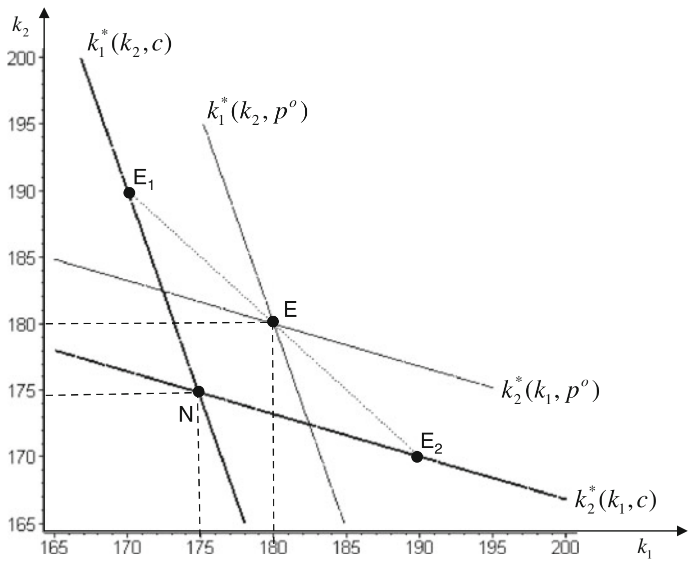

Fig. 3 Nash equilibrium and optimal transfer pricing in a pure profit center structure. The figure shows reaction functions $k_i^*(k_j, p)$ of division 1 and 2 for transfer price at full cost ($p = c$) and optimal transfer price ($p = p^o$). Points N and E denote the equilibrium capacities for $p = c$ and for $p = p^o$, respectively. The line connecting points E_1 and E_2 shows all efficient combinations of k_1 and k_2. Plot generated for $R_i = 300 \cdot q_i - 0.5 \cdot \varepsilon_i \cdot q_i^2, \varepsilon_i \in \{1, 2\}$ with equal probability, and $c = 45$

$$\Pi_2 = u_{21} \cdot \Pi_{21} + u_{22} \cdot \Pi_{22}, \tag{20}$$

where Π_{2t} is defined in Eq. (12). Dutta and Reichelstein argue that division 1 will find it "particularly profitable" to exaggerate its capacity demand in period 2 if $u_{22} > u_{21}$. The argument is intuitively appealing. As a profit center division 2 pays a price of p for each unit of excess capacity that it initially reserves. The ex ante cost incurred in period 1 must be overcompensated by the expected benefits realized in period 2. Since u_{22} and u_{21} can take arbitrary values, it is always possible to identify conditions, where this condition is met.

Interestingly, the hybrid organization can even provide incentives for strategic capacity planning in the context of a single period model where varying time preferences play no role by definition. The reason is that the hybrid organization changes the order of moves in the simultaneous capacity acquisition game and converts it into a sequential game. In the sequential game division 2 de facto becomes the Stackelberg leader. It reserves capacity k_2 before division 1 follows and acquires the total amount of capacity required by the two divisions. To elaborate on the consequences of this change, suppose that the firm plans only for a single period. With fungible capacity, the performance measure of division 1 in (6) becomes

$$\Pi_1 = \widehat{R}_1(k_1) + p \cdot k_2 - c \cdot (k_1 + k_2) + \delta_1 \cdot SP(k). \tag{21}$$

Maximizing the expression in (21) with respect to k_1 implicitly defines the optimal capacity of division 1 as a function of k_2. Solving the resulting first order condition for k_1 yields the reaction function $k_1^*(k_2)$ that specifies the best response of division 1 to a given capacity demand of division 2. Plugging the reaction function into the profit function of division 2 and maximizing the resulting expression with respect to k_2 yields the following condition for the optimal capacity choice of division 2:

$$\frac{d\Pi_2\left(k_2, k_1^*(k_2)\right)}{dk_2} = \frac{\partial \Pi_2}{\partial k_2} + \delta_2 \cdot \left[E[\lambda(k^*(k_2), \varepsilon)] - \widehat{R}_1'\left(k_1^*(k_2)\right)\right] \cdot \frac{dk_1}{dk_2} = 0, \tag{22}$$

where $k^*(k_2) = k_1^*(k_2) + k_2$. The last definition shows that division 2 essentially determines the total capacity of the firm. The expression in (22) comprises two terms. The term $\partial \Pi_2 / \partial k_2 \equiv \Pi_2'(k_2, k^*(k_2))$ captures the direct effect of marginally increasing k_2 on the profit of division 2. It is equivalent to the expression in the simultaneous move game in (13). The second term captures the first mover advantage. It comprises the marginal change in the profit of division 2 due to the reaction of division 1 on a marginal change of k_2. To determine the consequences of the strategic effect on the divisions' capacity choices, it is helpful to evaluate the optimality condition in (22) for the efficient capacity level and a transfer price at full cost.

Observe first that $\Pi_2'\left(k_2^o, k^o\right) = 0$ for $p = c$ whenever the shadow price is linear ε. Moreover, linearity implies that $E[\lambda(k^o, \varepsilon)] = \widehat{R}_1'\left(k_1^o\right)$ so that the strategic effect is also zero. It follows that the change in the order of moves does not impact the equilibrium outcome of the one period capacity game whenever the linearity condition in (11) is met. As shown in the previous section, $\Pi_2'\left(k_2^o, k^o\right)$ is nonzero if the shadow price is nonlinear in ε. In the profit center setting this fact motivates division 2 to secure too little capacity if $E[\lambda(k^o, \varepsilon)] > \widehat{R}'_i(k_i^o)$ and to reserve too much capacity otherwise. Since $dk_1/dk_2 < 0$, the strategic effect works into the same direction and reinforces the underinvestment problem caused by the violation of the linearity assumption. However, since division 2 is a profit center, the firm's central office can control its capacity demand by varying p. As for the pure profit center structure, there always exists a transfer price p^o that induces division 2 to reserve the efficient capacity level. Since the capacity decision of division 2 is biased in the same direction, p^o is below (above) full cost if division 2 reserves too little (too much) capacity.

To illustrate the argument, I continue the parametric example from Sect. 4.1 assuming identical bargaining powers. Figure 4 shows the potential equilibria in the divisions' capacity acquisition game. As in Fig. 3, the efficient capacity frontier is depicted by the line connecting E_1 and E_2, whereas the Nash equilibrium for a transfer price at full cost is marked by the intersection point N between the reaction functions $k_1^*(k_2)$ and $k_2^*(k_1)$. The Stackelberg equilibrium for the hybrid organization and a transfer price of $p = c$ is depicted by the tangency point S between the isoprofit curve of division 2, $\Pi_2(k_1, k_2, c)$, and the reaction function of division 1.

In the Stackelberg equilibrium division 2 reserves less capacity $\left(k_2^{*s} = 172.06\right)$, and division 1 reserves slightly more capacity $\left(k_1^{*s} = 175.75\right)$ than in the Nash equilibrium $\left(k_i^* = 174.86\right)$. Since the decrease in capacity demand of division 2

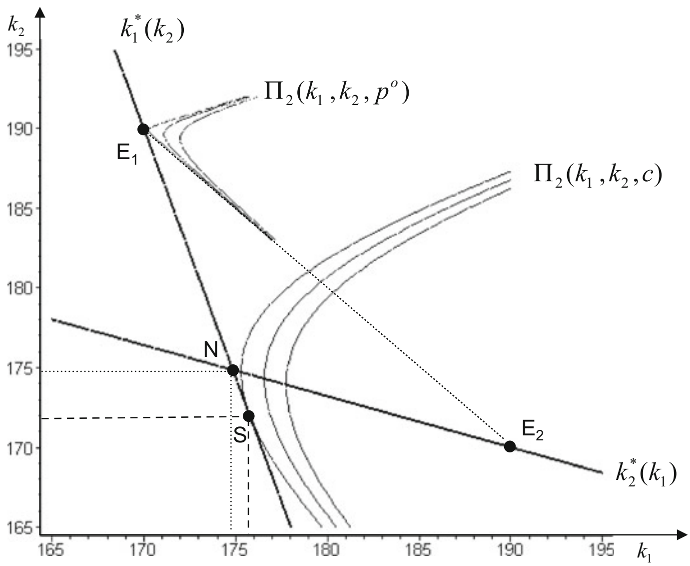

Fig. 4 Stackelberg equilibrium and optimal transfer pricing in a hybrid organization. The figure shows reaction functions $k_i^*(k_j)$ of division 1 and 2. $\Pi_2(k_1, k_2, p)$ are isoprofit curves for division 2 and a transfer price p. Point N depicts the Nash equilibrium for $p = c$. The line connecting points E_1 and E_2 shows all efficient combinations of k_1 and k_2. The tangency point S between $\Pi_2(k_1, k_2, c)$ and the reaction function of division 1 denotes the Stackelberg equilibrium for $p = c$. Point E_1 is the tangency point between $\Pi_2(k_1, k_2, p^o)$ and the reaction function of division 1. It marks the Stackelberg equilibrium for $p = p^o$. Plot generated for $R_i = 300 \cdot q_i - 0.5 \cdot \varepsilon_i \cdot q_i^2, \varepsilon_i \in \{1, 2\}$ with equal probability, and $c = 45$

exceeds the increase in capacity demand of division 1, total capacity drops from $k^* = 349.72$ to $k^{*s} = 347.81$. The example shows that the hybrid organization can exacerbate the underinvestment problem if shadow prices are nonlinear and the transfer price is at full cost.[14]

In the example, the central office can mitigate the problem if it sets a transfer price below full cost. Doing so shifts the isoprofit curve of division 2 to the northwest.[15] The optimal transfer price equals $p^o = 45 - 30 \cdot (1 - \delta_2)$. This expression is increasing in the bargaining power of division 2 and equals $p^o = 30$ for identical bargaining powers. The new equilibrium for $p = p^o$ is depicted by the tangency point E_1 between the isoprofit curve of division 2, $\Pi_2(k_1, k_2, p^o)$, and the reaction function of division 1. The resulting solution is efficient, that is, $k_1^{*s} + k_2^{*s} = k^o$.

The example confirms that the pure organizational forms dominate a hybrid organization if shadow prices are nonlinear and the firm sets its transfer prices on the basis of full cost. However, since the hybrid organization allows firms to mitigate the inefficiency caused by nonlinear shadow prices by adjusting the transfer price, it offers a clear advantage over an investment center structure where this option does not exist. Evidently, this argument is based on the results of a single period model with perfect information. However, the example shows that the ranking of organizational forms with nonlinear shadow prices is a nontrivial problem that deserves further consideration. Addressing this issue in the context of a multiperiod model with a richer set of transfer pricing methods is certainly promising.

4.3 Different capacity types and slack capacity

As explained in Sect. 2.1, the Dutta and Reichelstein model assumes that capacity is perfectly divisible and always fully utilized. These conditions significantly simplify the analysis of the multiperiod capacity planning problem, but they are not self-evident and require further discussion. A nontrivial capacity planning problem requires that some of the firm's resources cause costs that are fixed in the short run. Fixed capacity cost can arise for two reasons. First, the acquisition of capacity usually involves a long term commitment of resources and, second, the capacity resources can be indivisible (Luhmer 1992). As shown in Table 3, the combination of the two resource characteristics allows to distinguish four different resources types.

The first class of resources is perfectly divisible and immediately available as needed for production. These resources, such as materials or workers paid on a piece-rate basis, are not considered as capacities. Most capacity planning models including Dutta and Reichelstein and the capacity planning and pricing model discussed in Sect. 3.1 assume that the resources are perfectly divisible but

[14] The fact that the hybrid organization exacerbates the underinvestment problem can also be verified by comparing the orthogonal distances between the efficient capacity frontier and the equilibrium points N and S. In fact, this distance is larger for point S than for point N.

[15] A comparison of Figs. 3 and 4 shows that the procedure for implementing a new equilibrium via transfer pricing in a sequential game is different from the procedure for a simultaneous game. As shown in Fig. 3, the latter is based on a shift of reaction functions, while the former moves the tangency point between the reaction function of division 1 and the isoprofit curve of division 2.

Table 3 Resource and cost types

Resource type	Divisible	Indivisible
Flexible	Variable cost	Fixed cost (not traceable)
Commited	Fixed cost (traceable)	Fixed cost (not traceable)

Adapted from Luhmer (1992)

committed for a longer period. A natural example are permanent labor contracts. The cost of these resources is variable at the time of capacity planning but fixed once the capacity decision has been taken. Since capacity is perfectly scalable, the total acquisition cost can be traced to a single capacity unit and the per unit cost of capacity can be identified without ambiguity.

This attribute gets lost if resources are indivisible. Consider, for example, the acquisition of a patent for pharmaceuticals or an exclusive selling license and suppose that the seller demands a fixed annual fee. If the contract permits the buyer to market the respective product but does not relate the fee to the sales figures there is no link between the sales quantity and the cost of capacity. Moreover, if the potential market size is unknown, it is also impossible to determine a reliable measure for the acquisition cost per unit of the theoretical market capacity. Frequently, the acquisition of indivisible resources also involves long-term commitments. Under these conditions it is often hard to provide a theoretical justification for the allocation of the investment expenses to the single periods of the planning horizon. For example, if a firm buys a patent with a duration of multiple years but makes only one lump sum payment when signing the contract, it is impossible to relate the expenses in a meaningful manner to the sales quantities in single periods.

In practice, full costing typically involves the allocation of fixed costs caused by indivisible resources. By contrast, the capacity planning literature has almost exclusively focused on the relevance of perfectly divisible but committed resources. These resources are certainly important, but it remains an open question if unit cost measures derived from allocating the cost of indivisible resources can be helpful for facilitating capacity planning and capacity usage decisions.

By contrast, most theoretical studies allow for unused capacity resources (Van Mieghem 2003). Although firms in growing industries may indeed operate at full capacity for some years, there are many examples for firms that carry huge amounts of excess capacity because of unanticipated declines in demand, such as the automotive industry in the United States. It is therefore interesting to see if the structural insights of the Dutta and Reichelstein model would change if the firm could carry unused capacity. Answering this question would require a more detailed analysis of capacity use. Currently, capacity use is not explicitly modeled but implicitly incorporated in the reduced form revenue function.

In fact, this approach is not too restrictive because the capacity planning and pricing model discussed in Sect. 3.1 shows that a more detailed analysis of capacity planning and capacity use leads to similar reduced form profit functions at the capacity planning stage. The main difference between the two approaches lies in the fact that the capacity constraint does not bind for some realizations of the noise term ε_t. Let Ω denote the set of realizations for which the product demand is lower than capacity and let $\overline{\Omega}$ define its complement. Clearly, the maximum revenue R^*_{it} does not depend on k_t, and the shadow price of capacity is zero for all $\varepsilon_t \in \Omega$. Accordingly, the maximum revenue of division i in period t must be redefined and becomes

$$\widehat{R}^*_{it} = E_{\varepsilon_t|\varepsilon_t \in \overline{\Omega}}[R_i(q_{it}(k_t, \varepsilon_t), \varepsilon_{it})] + E_{\varepsilon_t|\varepsilon_t \in \Omega}[R_i(q_{it}(\varepsilon_{it}), \varepsilon_{it})]. \tag{23}$$

This expression is still a function of k_t. Likewise, the expected opportunity cost becomes $E_{\varepsilon_t|\varepsilon_t \in \overline{\Omega}}[\lambda(k_t, \varepsilon_t)]$, but this modification does not change the structure of the optimality condition in (10) although the optimal capacity will generally be different.[16] I conclude that the structural insights of the Dutta and Reichelstein model remain valid even if the capacity constraint does not always bind.

5 Summary and conclusions

Dutta and Reichelstein provide a rich and interesting study of the interplay between transfer pricing and organizational form in providing incentives for efficient capacity management in decentralized firms. Their analysis yields two important findings. First, transfer prices based on the historical cost of capacity can be a useful instrument for implementing efficient capacity decisions in decentralized organizations. Second, symmetric responsibility structures are generally better suited for providing efficient investment incentives than hybrid organizations.

The key prerequisite for establishing these results is the efficiency of the adjustable full cost transfer pricing mechanism in the fungible capacity scenario. Dutta and Reichelstein clearly state that this condition is only met if the shadow price of capacity is a linear function of the noise terms in the divisions' revenue function, but they do not explore the consequences of this restriction on the optimal transfer price and the ranking of organizational forms.

My analysis in Sects. 4.1 and 4.2 yields two additional insights for a world in which the shadow prices of capacity are nonlinear. First of all, the negotiated transfer pricing mechanism is still essential for implementing efficient capacity decisions, but it is no longer optimal to base the initial transfer price on full cost. In fact, it is usually better to use a transfer price below (above) the historical cost of capacity in order to counteract the managers' incentives to underinvest (overinvest). Second, since the transfer price becomes an important instrument for mitigating the inefficiency caused by nonlinear shadow prices, profit center organizations are generally more appropriate for motivating the managers to acquire the efficient capacity levels than investment center organizations. The additional degree of freedom in guiding the managers' capacity decision can even make a hybrid organization more desirable than a pure investment center structure. However, this

[16] In fact, an equivalent optimality condition for the capacity planning stage can be found in the model of Göx (2002), Eq. (44) that allows for unused capacity.

argument is based on the analysis of a simple single period model with perfect information and cannot be generalized.

More fundamentally, this discussion shows that the curvature of profit functions can have an important impact on optimal transfer pricing and organizational design. This observation is an important by-product of the Dutta and Reichelstein model that significantly increases the complexity of transfer pricing models and clearly deserves further consideration. Addressing this issue in the context of a multiperiod model with a richer set of transfer pricing methods is certainly a promising objective for future research in the area of transfer pricing.

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